Phasing the Cost Estimate

OS 4012

Phasing the Cost Estimate

- At the end of this presentation we will have covered:
  - Various methods used to phase cost estimates
  - Converting a cost profile to a budget profile
  - How to allocate a p^{th} percentile cost estimate back to the WBS so that they all add up correctly

Introduction

- Schedule estimation is not normally done by cost analysts, but we should be able to spread a cost estimate over time.
- In a few moments, we will discuss spreading a cost estimate to match a schedule estimate.
- But, to understand scheduling, it is useful to learn about DoD Appropriations and and DoD funding policies.

Appropriations

- In order to execute an acquisition program, Congress must provide ***budget authority***.
  - Necessary to incur obligations and make payments
- Budget authority is provided via an ***appropriations act***, in which Congress specifies the *purpose* of the appropriation as well as the *amount* of budget authority granted for each appropriation.
- DoD receives many appropriations, most of which can be grouped by:
  - Research, Development, Test and Evaluation (RDT&E)
  - Procurement
  - Operations & Maintenance (O&M)
  - Military Personnel (MILPERS)
  - Military Construction (MILCON)

RDT&E Appropriation

- This appropriation finances RDT&E efforts performed by contractors and government installations for:
  - Equipment, material, or computer application software development;
  - Developmental Test and Evaluation (DT&E);
  - Initial Operational Capability (IOC)
- Includes purchases of end items, weapons, equipment, components, and materials, as well as performance of services.
  - Whatever is necessary to develop and test the system.
- RDT&E funds are also used to pay the operating costs of dedicated activities engaged in the conduct of research and development programs.

Procurement Appropriation

- This appropriation finances investment items, and should cover all costs integral and necessary to deliver a useful end item intended for operational use or inventory:
  - Shipbuilding and conversion
  - Aircraft procurement
  - Missile procurement
  - Etc.
- The cost of fabricating and installing additions or modifications to existing end items is also funded with procurement appropriations.

O&M Appropriation

- O&M Appropriations traditionally finance those things whose benefits are derived for a limited period of time.
  - Expenses rather than investments
- Examples include:
  - Headquarters operations
  - Civilian salaries and awards
  - Travel
  - Fuel
  - Minor construction projects
  - Expenses of operational military forces
  - Training and education
  - Recruiting
  - Depot maintenance
  - Base operations support

MILPERS Appropriation

- Similar to O&M in that they finance expenses rather than investments.
- Used to fund:
  - Salaries and compensation for active military and National Guard personnel
  - Permanent Change of Duty Station
  - Training in conjunction with PCS moves
  - Subsistence
  - Temporary lodging
  - Bonuses
  - Retired pay accrual

MILCON Appropriation

- These appropriations fund the costs of major construction projects such as
  - Bases
  - Facilities
  - Military schools
  - Architecture and engineering services
  - Construction design
  - Real property acquisition
  - Missile storage facilities
  - Intermediate maintenance facilities
  - Medical/dental clinics
  - Technical libraries
  - Physical fitness training centers

Financial Rules and Practice

- DoD financial rules are derived from Congressional direction concerning the amount and timing of budget requests for different appropriations.
- These funding policies serve to ration scarce budget authority among DoD’s many activities and programs.
- Types of funding include:
  - Annual Funding
  - Incremental Funding
  - Full Funding

Annual Funding

- The *Annual Funding* policy governs *O&M* and *MILPERS* Appropriations.
- The policy requires that financial managers request only the dollars needed to operate, maintain, or pay forces in a *given fiscal year*.
- Major exception to this policy is a provision allowing financing of service contracts whose period of performance crosses fiscal years.
- As long as these service contracts are 12 months or less in duration, then DoD may fund the entire period of performance with funds available for obligation at the time of contract award.
  - For example, a service contract covering the period April 2007 through March 2008 (12 months, starting in FY07 and ending in FY08) may be funded entirely with FY07 funds.

Incremental Funding

- The *Incremental Funding* policy governs budgeting of *RDT&E* Appropriations.
- Only those funds required for work in a given fiscal year shall be included in the RDT&E budget request for that fiscal year.
- Example:

	FY12	FY13	FY14	FY15
Project 1 $350K	$200K	$100K	$50K	
Project 2 $200K		$40K	$120K	$40K
Project 3 $100K		$10K	$60K	$30K
Budget Request	??	??	??	??

Incremental Funding Example

- Assume the costs shown previously are expressed in constant FY11$
  - That is, the costs are estimated in ***today's*** dollars
- In order to plan a budget, we need to account for inflation in each of those years
- Assume 3.1% annual inflation for the next few years
  - For FY12, multiply each cost by (1.031)
  - For FY13, multiply each cost by $(1.031)^2$
  - For FY14, multiply each cost by $(1.031)^3$, and so on…

All Costs expressed in FY11$				
	FY12	FY13	FY14	FY15
Project 1 $350K (FY11$)	$ 200	$ 100	$ 50	$ -
Project 2 $200K (FY11$)	$ -	$ 40	$ 120	$ 40
Project 3 $100K (FY11$)	$ -	$ 10	$ 60	$ 30
Budget Request (FY11$)	**$ 200**	**$ 150**	**$ 230**	**$ 70**

All Costs expressed in TY$ (using 3.1% inflation)				
	FY12	FY13	FY14	FY15
Project 1 $350K (FY11$)	$ 206	$ 106	$ 55	$ -
Project 2 $200K (FY11$)	$ -	$ 43	$ 132	$ 45
Project 3 $100K (FY11$)	$ -	$ 11	$ 66	$ 34
Budget Request (TY$)	**$ 206**	**$ 159**	**$ 252**	**$ 79**

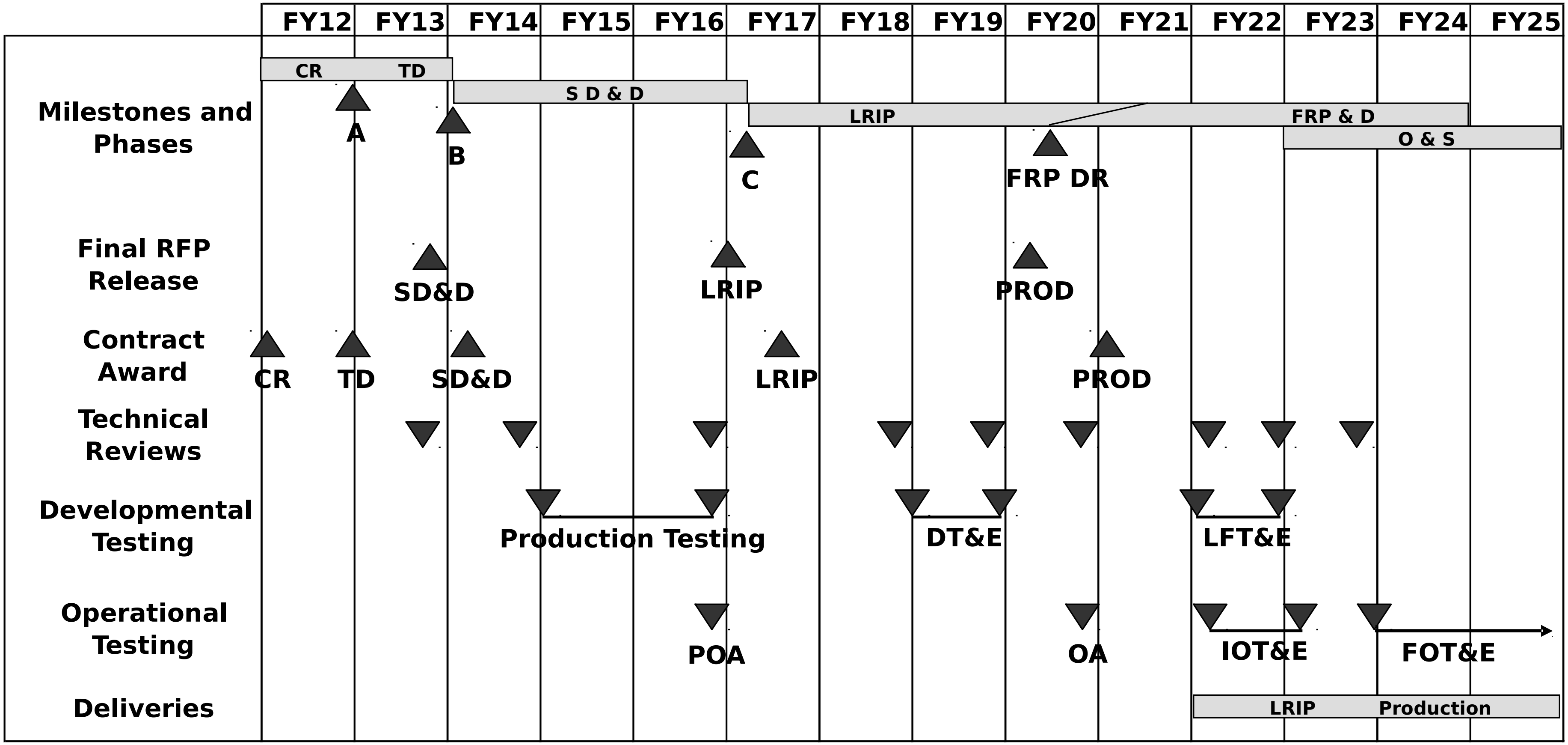
Full Funding

- The *Full Funding* policy governs budgeting of *Procurement* and *MILCON* Appropriations.
- This is the practice of funding the *total cost* of major procurement and construction projects in the fiscal year in which they will be *initiated*.
- The Full Funding policy ensures funding each fiscal year in order to procure a *complete, usable end item*.
  - That is, an end item budgeted for in one fiscal year may not depend on a future year’s funding to complete its procurement.
  - Thus, piecemeal procurement of systems is not permitted.
  - Prevents DoD from ending up with unusable parts or components if a program is cancelled or interrupted.
- All funds required to complete the delivery of each buy are included in the budget request for the year of the planned contract award, regardless of the date of the actual delivery.

Multi-Year Procurement

- *Multi-year procurement (MYP)* is an exception to the full funding policy.
- MYP is a vehicle for acquiring funding for multiple years, usually up to a maximum of five years, with a single contract.
- The purpose of MYP is to reduce program cost growth and introduce stability into the acquisition process.
  - It does this by making a commitment to the contractor to procure a specific quantity of a weapon system over several years, to be funded on a year-by-year basis.
  - The contractor is incentivized to realize saving through economic order quantity purchases and investment in productivity enhancements.

Typical Program Schedule



Spreading Cost to a Schedule

- When a schedule such as the one on the preceding slide is available, it is relatively easy to spread the cost estimate.
  - Spread the cost relative to the milestones, phases, and activities.
- This is not always the case, however. When it is too early to develop a schedule, then we resort to heuristic methods, and typical outlay profiles.

Translating Cost to an Expenditure Profile

- Cost estimates are normally developed in constant year dollars.
  - Ignores effect of inflation and "color of money"
- However, expenditure profiles must take both of these effects into consideration, requiring translation of constant dollars into then-year dollars.
- Before translating a cost estimate into an expenditure profile, it is necessary to develop a program master schedule.
  - This is the responsibility of the program manager, NOT the cost analyst.
- The master schedule reflects the work breakdown structure
  - Showing when each task begins and ends
  - How the tasks are related to one another
  - How the workload for each task is distributed over time
- Requires a reliable estimate of the time required to complete each task, and the sequence in which they must be executed.

Translating Cost to an Expenditure Profile

- With an estimate of the cost of each task, and the time-phasing of those tasks, it is then possible to phase the cost estimate so that the anticipated expenditure profile can be determined.
- It is important to evaluate each cost element to determine which appropriation (or “color of money”) should be used to fund those tasks in order to comply with applicable funding policies.

Time-Phasing Development

- Say you are estimating the cost of a new automated information management system (AIMS).
- Your development program is projected to last four years.
- Your development CERs have provided you with the total development cost.

- Now, for programming and budgeting purposes, you must identify your resource requirements by fiscal year. How will you allocate the development costs over the four years?

Note: Whenever dollars are being spread across two or more fiscal years, the calculations must be performed in base year or constant year dollars.

Time-Phasing Development

- While PRODUCTION can be said to be *product oriented* in its funding approach, DEVELOPMENT is more *process oriented*.
- This means cost has to be tied to the *process* of development which includes system requirements review, preliminary design review, critical design review, software coding, system tests, etc.
- *Incremental Funding* is the policy that is used for development.

AIMS Work Breakdown Structure

WBS Element	FY11$K	
Prime Mission Equipment	$ 40,000	
Hardware		$ 12,500
Software		$ 27,500
Engineering Change Orders	$ 8,000	
System Engineering/Program Mgmt	$ 11,000	
Government Furnished Equipment	$ 2,500	
Training	$ 2,200	
Peculiar Support Equipment	$ 4,400	
Test & Evaluation	$ 8,800	
Data	$ 1,350	
Total Cost	**$ 78,250**	

2012 2013 2014 2015

Fiscal Spread by Program Schedule

- This technique involves the following process of developing schedules and milestones:
  - Determine the milestones.
  - Time phase milestones based on the program schedule.
  - Estimate percent of total cost required to complete each milestone.
  - Allocate cost to appropriate fiscal year(s).

Step 1 - Determine Milestones

- Select those milestones which are most quantifiable.
- In our example we will use:

Contract Award
Critical Design Review
Prototype Fabrication and Assembly
  - Hardware
    - Fabricate
    - Assemble
    - Test
  - Software
    - Coding
    - Test
  - System Integration and Test

Contractor Developmental T & E
Production Readiness Review
Government Developmental T & E

Step 2 - Time Phase Milestones

Milestone	Program Month	Actual Month	Fiscal Year
Contract Award	0	Oct 12	FY12
Critical Design Review	7	Apr 12	FY12
Prototype Fabrication and Assembly	8 - 31	May 12 - Apr 14	FY12 - FY14
Hardware			
Fabricate	8 - 19	May 12 - Apr 13	FY12 - FY13
Assemble	20 - 26	May 13 - Nov 13	FY13 - FY14
Test	27 - 29	Dec 13 - Feb 14	FY14
Software			
Coding	8 - 24	May 12 - Sep 13	FY12 - FY13
Test	25 - 29	Oct 13 - Feb 14	FY14
System Integration and Test	30 - 31	Mar 14 - Apr 14	FY14
Contractor Developmental T & E	32 - 37	May 14 - Oct 14	FY14 - FY15
Production Readiness Review	40	Jan 15	FY15
Government Developmental T & E	41 - 44	Feb 15 - May 15	FY15

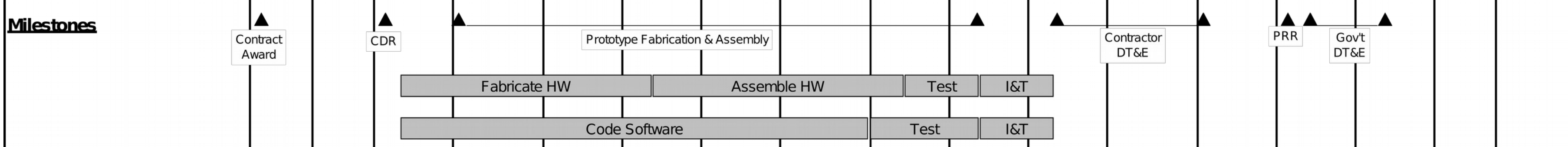
Step 2 - Time Phase Milestones

Fiscal Year	FY12				FY13				FY14				FY15				Estimate
Quarter	1Q12	2Q12	3Q12	4Q12	1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14	1Q15	2Q15	3Q15	4Q15	FY11$K
Milestones	Contract Award		CDR		Prototype Fabrication & Assembly							Contractor DT&E		PRR	Gov't DT&E		
				Fabricate HW				Assemble HW	Test	I&T							
						Code Software			Test	I&T							
WBS Elements																	
Prime Mission Equipment																	$ 40,000
Hardware																	$ 12,500
Software																	$ 27,500
ECO																	$ 8,000
Sys Eng / Prgm Mgmt																	$ 11,000
Govt Furnished Equip																	$ 2,500
Training																	$ 2,200
Peculiar Support Equip																	$ 4,400
Test & Eval																	$ 8,800
Data																	$ 1,350
Total																	$ 78,250

Step 3 – Estimate Cost Percentages

Fiscal Year	FY12				FY13				FY14				FY15				Estimate
Quarter	**1Q12**	**2Q12**	**3Q12**	**4Q12**	**1Q13**	**2Q13**	**3Q13**	**4Q13**	**1Q14**	**2Q14**	**3Q14**	**4Q14**	**1Q15**	**2Q15**	**3Q15**	**4Q15**	**FY11$K**
Milestones	Contract Award		CDR			Prototype Fabrication & Assembly						Contractor DT&E		PRR	Gov't DT&E		
			Fabricate HW			Assemble HW			Test	I&T							
			Code Software						Test	I&T							
WBS Elements																	
Prime Mission Equipment																	$ 40,000
Hardware			10%	20%	15%	10%	15%	10%	5%	3%	2%	5%		3%	2%		$ 12,500
Software			10%	25%	15%	10%	10%	5%	10%		5%	5%		3%	2%		$ 27,500
ECO					10%			40%				40%			10%		$ 8,000
Sys Eng / Prgm Mgmt	5%	5%	10%	5%	5%	5%	5%	5%	10%	10%	10%	10%	5%	5%	5%		$ 11,000
Govt Furnished Equip								100%									$ 2,500
Training												20%	40%	20%	20%		$ 2,200
Peculiar Support Equip			5%	5%		30%		25%		15%	10%	5%			5%		$ 4,400
Test & Eval			5%	5%				10%	10%	10%	5%	35%		10%	10%		$ 8,800
Data				30%				30%				30%			10%		$ 1,350
Total																	$ 78,250

Step 4 – Convert Percentages to Cost



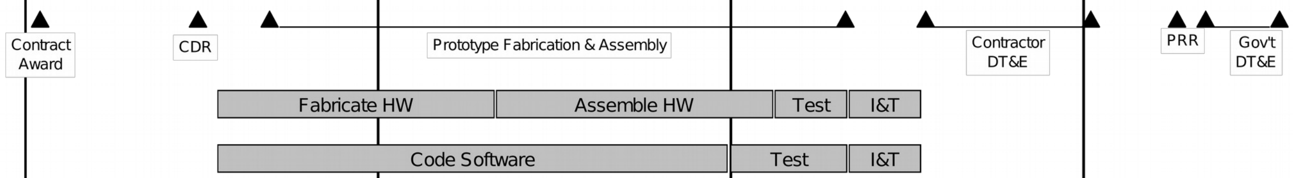
Fiscal Year	**FY12**				**FY13**				**FY14**				**FY15**				**Estimate**
Quarter	**1Q12**	**2Q12**	**3Q12**	**4Q12**	**1Q13**	**2Q13**	**3Q13**	**4Q13**	**1Q14**	**2Q14**	**3Q14**	**4Q14**	**1Q15**	**2Q15**	**3Q15**	**4Q15**	**FY11$K**
WBS Elements																	
Prime Mission Equipment	$ -	$ -	$ 4,000	$ 9,375	$ 6,000	$ 4,000	$ 4,625	$ 2,625	$ 3,375	$ 375	$ 1,625	$ 2,000	$ -	$ 1,200	$ 800	$ -	**$ 40,000**
Hardware	$ -	$ -	$ 1,250	$ 2,500	$ 1,875	$ 1,250	$ 1,875	$ 1,250	$ 625	$ 375	$ 250	$ 625	$ -	$ 375	$ 250	$ -	**$ 12,500**
Software	$ -	$ -	$ 2,750	$ 6,875	$ 4,125	$ 2,750	$ 2,750	$ 1,375	$ 2,750	$ -	$ 1,375	$ 1,375	$ -	$ 825	$ 550	$ -	**$ 27,500**
ECO	$ -	$ -	$ -	$ -	$ 800	$ -	$ -	$ 3,200	$ -	$ -	$ -	$ 3,200	$ -	$ -	$ 800	$ -	**$ 8,000**
Sys Eng / Prgm Mgmt	$ 550	$ 550	$ 1,100	$ 550	$ 550	$ 550	$ 550	$ 550	$ 1,100	$ 1,100	$ 1,100	$ 1,100	$ 550	$ 550	$ 550	$ -	**$ 11,000**
Govt Furnished Equip	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,500	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	**$ 2,500**
Training	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 440	$ 880	$ 440	$ 440	$ -	**$ 2,200**
Peculiar Support Equip	$ -	$ -	$ 220	$ 220	$ -	$ 1,320	$ -	$ 1,100	$ -	$ 660	$ 440	$ 220	$ -	$ -	$ 220	$ -	**$ 4,400**
Test & Eval	$ -	$ -	$ 440	$ 440	$ -	$ -	$ -	$ 880	$ 880	$ 880	$ 440	$ 3,080	$ -	$ 880	$ 880	$ -	**$ 8,800**
Data	$ -	$ -	$ -	$ 405	$ -	$ -	$ -	$ 405	$ -	$ -	$ -	$ 405	$ -	$ -	$ 135	$ -	**$ 1,350**
Total	**$ 550**	**$ 550**	**$ 5,760**	**$ 10,990**	**$ 7,350**	**$ 5,870**	**$ 5,175**	**$ 11,260**	**$ 5,355**	**$ 3,015**	**$ 3,605**	**$ 10,445**	**$ 1,430**	**$ 3,070**	**$ 3,825**	**$ -**	**$ 78,250**

Step 5 – Allocate Costs by FY

Fiscal Year	FY12	FY13	FY14	FY15	Estimate FY11$K
Milestones	Contract Award, CDR	Prototype Fabrication & Assembly	Contractor DT&E	PRR, Gov't DT&E	
	Fabricate HW	Assemble HW	Test, I&T		
	Code Software		Test, I&T		
WBS Elements					
Prime Mission Equipment	$ 13,375	$ 17,250	$ 7,375	$ 2,000	**$ 40,000**
Hardware	$ 3,750	$ 6,250	$ 1,875	$ 625	**$ 12,500**
Software	$ 9,625	$ 11,000	$ 5,500	$ 1,375	**$ 27,500**
ECO	$ -	$ 4,000	$ 3,200	$ 800	**$ 8,000**
Sys Eng / Prgm Mgmt	$ 2,750	$ 2,200	$ 4,400	$ 1,650	**$ 11,000**
Govt Furnished Equip	$ -	$ 2,500	$ -	$ -	**$ 2,500**
Training	$ -	$ -	$ 440	$ 1,760	**$ 2,200**
Peculiar Support Equip	$ 440	$ 2,420	$ 1,320	$ 220	**$ 4,400**
Test & Eval	$ 880	$ 880	$ 5,280	$ 1,760	**$ 8,800**
Data	$ 405	$ 405	$ 405	$ 135	**$ 1,350**
Total	$ 17,850	$ 29,655	$ 22,420	$ 8,325	**$ 78,250**

Step 6 – Adjust for Inflation

Fiscal Year	FY12	FY13	FY14	FY15	Estimate
Inflation Rate	3.10%	3.10%	3.10%	3.10%	TY11$K
Milestones					
WBS Elements					
Prime Mission Equipment	$ 13,790	$ 18,336	$ 8,082	$ 2,260	**$ 42,468**
Hardware	$ 3,866	$ 6,644	$ 2,055	$ 706	**$ 13,271**
Software	$ 9,923	$ 11,693	$ 6,028	$ 1,554	**$ 29,197**
ECO	$ -	$ 4,252	$ 3,507	$ 904	**$ 8,663**
Sys Eng / Prgm Mgmt	$ 2,835	$ 2,339	$ 4,822	$ 1,864	**$ 11,860**
Govt Furnished Equip	$ -	$ 2,657	$ -	$ -	**$ 2,657**
Training	$ -	$ -	$ 482	$ 1,989	**$ 2,471**
Peculiar Support Equip	$ 454	$ 2,572	$ 1,447	$ 249	**$ 4,721**
Test & Eval	$ 907	$ 935	$ 5,786	$ 1,989	**$ 9,618**
Data	$ 418	$ 430	$ 444	$ 153	**$ 1,444**
Total	$ 18,403	$ 31,522	$ 24,570	$ 9,406	**$ 83,902**



Results of Fiscal Spread

- Since this method is tied to the program schedule it can be fairly easily defended.

- However, if the program is not yet developed to any level of detail, then the analyst must either pursue development of the schedule or look for another methodology.

Time Phasing Production

- Until now we have focused on time-phasing an estimate in the *development* stage. The next step is to address spreading the *production* estimate over time.
- The *full funding policy* is generally used in procurement.
- If production spans 10 years, where in the 10 year production schedule do you allocate costs?

Outlay Profiles

- To estimate the profile of how those costs will be outlaid over time, we use DoD historical outlay rates based on similar programs and appropriations.
- These are the same outlay profiles used in the calculation of weighted inflation indices.
- There is a time lag between the creation of budget authority and outlays that flow from that budget authority. The table below reflects outlay rates for

Navy	First Year	Second Year	Third Year	Fourth Year	Fifth Year	Sixth Year	Seventh Year
Aircraft Procurement	20.00%	41.00%	28.00%	6.90%	2.50%	1.60%	
Shipbuilding and Conversion	17.34%	23.57%	21.19%	19.69%	10.13%	7.66%	0.42%
RDT&E	51.01%	38.65%	8.06%	1.31%	0.97%		

Outlay Profile Method

- The outlay profile method can be used to fiscally spread a cost estimate for a production program.
- In a production program where multiple lots are being produced over multiple years, this has the effect of converting a *cost estimate* into a *budget profile*.
- Consider an aircraft production program in which 500 aircraft are to be procured over a 10 year period at a cost of $11.5B (FY11$).
- Historically, it takes six years to expend all of the funds obligated in an aircraft production contract. So, for a production run that consists of five lots, each beginning in contiguous years, the program office can plan on providing funding for 10 years. See example, next page.

Phasing the Cost Estimate

Fiscal Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	TOTAL
Lot Qty Ordered	50	100	200	100	50						500
Cost Estimate (BY$M)	**$ 1,627**	**$ 2,503**	**$ 4,342**	**$ 2,012**	**$ 980**						**$ 11,463**

Lot Cost Estimates (without Outlay Profiles)

Fiscal Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	TOTAL
Lot 1 Cost Estimate	$ 1,627										$ 1,627
Lot 2 Cost Estimate		$ 2,503									$ 2,503
Lot 3 Cost Estimate			$ 4,342								$ 4,342
Lot 4 Cost Estimate				$ 2,012							$ 2,012
Lot 5 Cost Estimate					$ 980						$ 980

Aircraft Procurement Outlay Profiles

Budget Year	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	TOTAL
Lot 1 Outlay Profile	20.0%	41.0%	28.0%	6.9%	2.5%	1.6%					100%
Lot 2 Outlay Profile		20.0%	41.0%	28.0%	6.9%	2.5%	1.6%				100%
Lot 3 Outlay Profile			20.0%	41.0%	28.0%	6.9%	2.5%	1.6%			100%
Lot 4 Outlay Profile				20.0%	41.0%	28.0%	6.9%	2.5%	1.6%		100%
Lot 5 Outlay Profile					20.0%	41.0%	28.0%	6.9%	2.5%	1.6%	100%

Lot Cost Estimates (with Outlay Profiles)

Fiscal Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	TOTAL
Lot 1 Cost Estimate	$ 325	$ 667	$ 455	$ 112	$ 41	$ 26					$ 1,627
Lot 2 Cost Estimate		$ 501	$ 1,026	$ 701	$ 173	$ 63	$ 40				$ 2,503
Lot 3 Cost Estimate			$ 868	$ 1,780	$ 1,216	$ 300	$ 109	$ 69			$ 4,342
Lot 4 Cost Estimate				$ 402	$ 825	$ 563	$ 139	$ 50	$ 32		$ 2,012
Lot 5 Cost Estimate					$ 196	$ 402	$ 274	$ 68	$ 24	$ 16	$ 980
Phased Cost Estimate (BY$M)	**$ 325**	**$ 1,168**	**$ 2,350**	**$ 2,996**	**$ 2,450**	**$ 1,353**	**$ 562**	**$ 187**	**$ 57**	**$ 16**	**$ 11,463**

Inflating the Cost Estimate

- Now that the estimate is properly phased, we apply inflation at the rate of 3.1% per year.

Lot Cost Estimates (with Outlay Profiles)											
Fiscal Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**TOTAL**
Lot 1 Cost Estimate	$ 325	$ 667	$ 455	$ 112	$ 41	$ 26					$ 1,627
Lot 2 Cost Estimate		$ 501	$ 1,026	$ 701	$ 173	$ 63	$ 40				$ 2,503
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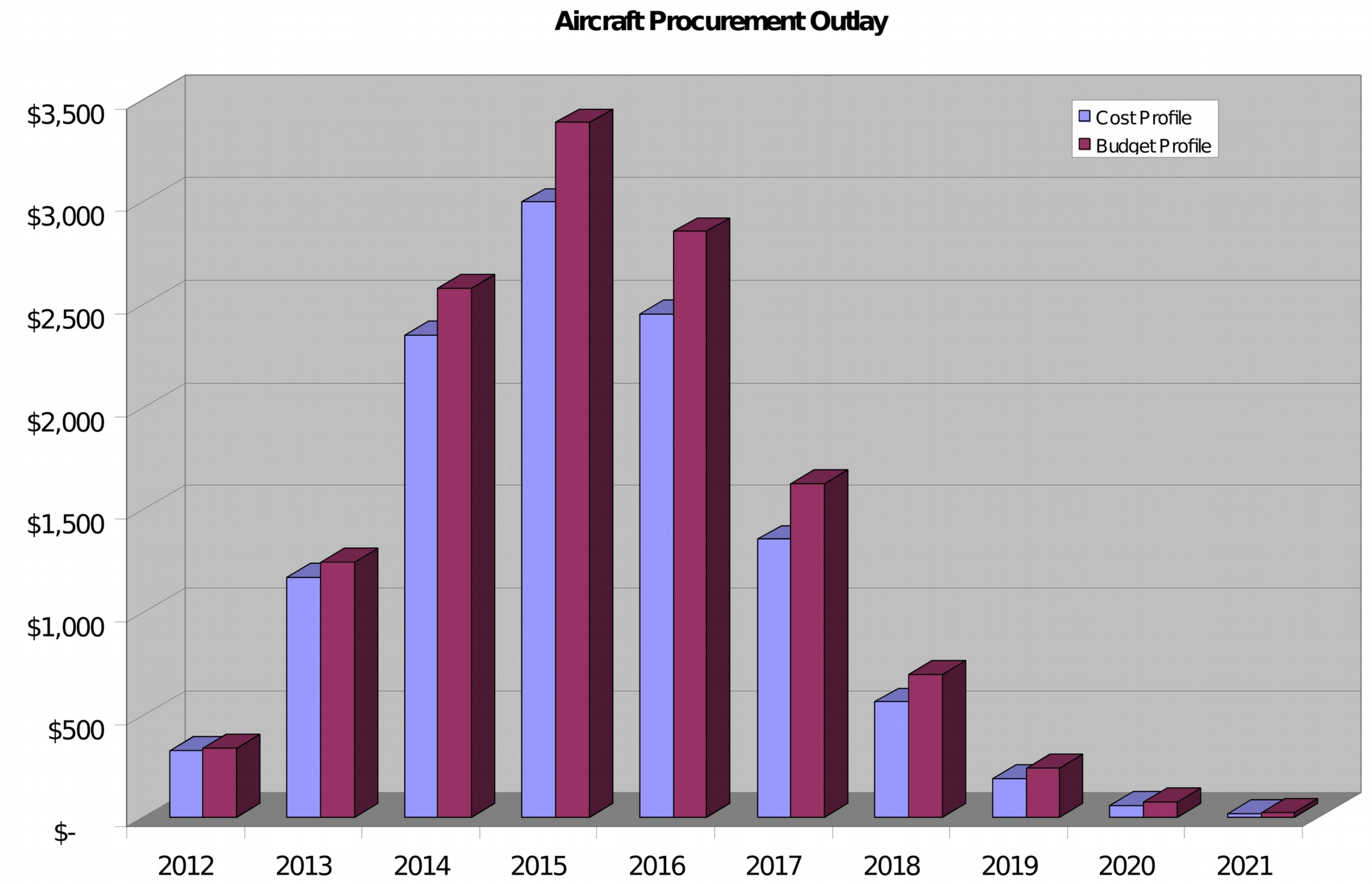
Phased Cost Estimate (BY$M)	**$ 325**	**$ 1,168**	**$ 2,350**	**$ 2,996**	**$ 2,450**	**$ 1,353**	**$ 562**	**$ 187**	**$ 57**	**$ 16**	**$ 11,463**

Inflation	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Projected Inflation Rate	3.10%	3.10%	3.10%	3.10%	3.10%	3.10%	3.10%	3.10%	3.10%	3.10%

Lot Cost Estimates (Then-Year Dollars)											
Fiscal Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**TOTAL**
Lot 1 Cost Estimate	$ 335	$ 709	$ 499	$ 127	$ 47	$ 31					$ 1,749
Lot 2 Cost Estimate		$ 532	$ 1,125	$ 792	$ 201	$ 75	$ 50				$ 2,774
Lot 3 Cost Estimate			$ 952	$ 2,011	$ 1,416	$ 360	$ 134	$ 89			$ 4,962
Lot 4 Cost Estimate				$ 455	$ 961	$ 677	$ 172	$ 64	$ 42		$ 2,371
Lot 5 Cost Estimate					$ 228	$ 482	$ 340	$ 86	$ 32	$ 21	$ 1,190
Budget Estimate (TY$M)	**$ 335**	**$ 1,241**	**$ 2,575**	**$ 3,385**	**$ 2,854**	**$ 1,625**	**$ 696**	**$ 239**	**$ 75**	**$ 21**	**$ 13,046**

Budget Profile



Early Phase Acquisition Phasing

- In early phases of acquisition, detailed development and production schedules are unknown.
- In these cases, we resort to approximations based on heuristics.
- What is usually available:
  - ROM cost estimate
  - Approximate number of years to develop and field
  - E.g., “It will cost about $1.0B, and take about 10 years to acquire.”
- How do we phase this type of estimate?

Time Spreading of ROM Estimates

- **Source:** *Wynholds & Skratt [1977], as published in Space Mission Analysis and Design, 3rd Edition*

- The following heuristic cost spreading method approximates the experience of actual programs.

- The spreading of costs to determine funding profiles can be approximated by a function of the form:

-

$$\boxed{F(S) = A\left[10 + S\left(\left(15 - 4S\right)S - 20\right)\right]S^2 + B\left[10 + S\left(6S - 15\right)\right]S^3 + \left[1 - \left(A + B\right)\right]\left(5 - 4S\right)S^4}$$

- where *F(S)* is the fraction of cost consumed in time *S*, *S* is the fraction of the total time elapsed, and *A* and *B* are empirical coefficients.

- The values for coefficients *A* and *B* depend on the expected loading of costs over time...Typically, 60% of the costs will be incurred by the midpoint of the schedule.

Time Spreading of ROM Estimates

- This method can be used to develop an approximate phasing profile for any cost estimate over any specified number of years.

Total Cost (BY$M)	$ 1,000
Inflation Rate	3.1%
Pct Expenditure at Schedule Midpoint	60%
Number of Years	10

Percent expenditure at schedule midpoint	**Coefficients in *F(S)***	
	A	***B***
20%	0.00	0.04
40%	0.00	0.68
50%	0.00	1.00
60%	0.32	0.68
80%	0.96	0.04

Year	***S***	***F(S)***	**Total Expended (BY$M)**	**Annual Expended (BY$M)**	**Inflation**	**Annual Expended (TY$M)**
2008	0.10	0.032	$ 32	$ 32	3.10%	$ 33
2009	0.20	0.123	$ 123	$ 92	3.10%	$ 97
2010	0.30	0.262	$ 262	$ 138	3.10%	$ 152
2011	0.40	0.428	$ 428	$ 166	3.10%	$ 188
2012	0.50	0.600	$ 600	$ 172	3.10%	$ 200
2013	0.60	0.756	$ 756	$ 156	3.10%	$ 188
2014	0.70	0.879	$ 879	$ 123	3.10%	$ 152
2015	0.80	0.958	$ 958	$ 79	3.10%	$ 101
2016	0.90	0.994	$ 994	$ 36	3.10%	$ 47
2017	1.00	1.000	$ 1,000	$ 6	3.10%	$ 8

Time Spreading of ROM Estimates

- Implementation Example:

Time Spreading of Costs (from *Space Mission Analysis & Design, 3rd Ed.*, paragraph 20.4.2)

The following analytical cost spreading method was developed by Wynholds and Skratt [1977] and approximates the experience of actual programs.

The spreading of costs to determine funding profiles can be approximated by a function of the form:

$$F(S) = A[10+S((15-4S)S-20)]S^2 + B[10+S(6S-15)]S^3 + [1-(A+B)](5-4S)S^4$$

where $F(S)$ is the fraction of cost consumed in time S, S is the fraction of the total time elapsed, and A and B are empirical coefficients.

The values for coefficients A and B depend on the expected loading of costs over time...Typically, 60% of the costs will be incurred by the midpoint of the schedule. The coefficients for various spending splits are shown at right.

Percent expenditure at schedule midpoint	Coefficients in *F(S)*	
	A	***B***
20%	0.00	0.04
40%	0.00	0.68
50%	0.00	1.00
60%	0.32	0.68
80%	0.96	0.04

Do not change these values

Total Cost (BY$M)	$ 1,000
Inflation Rate	3.1%
Start Year (e.g., 2007)	2012
End Year (e.g., 2009)	2019
Pct. Expenditure at Schedule Midpoint (20%, 40%, 50%, 60%, 80%)	60%

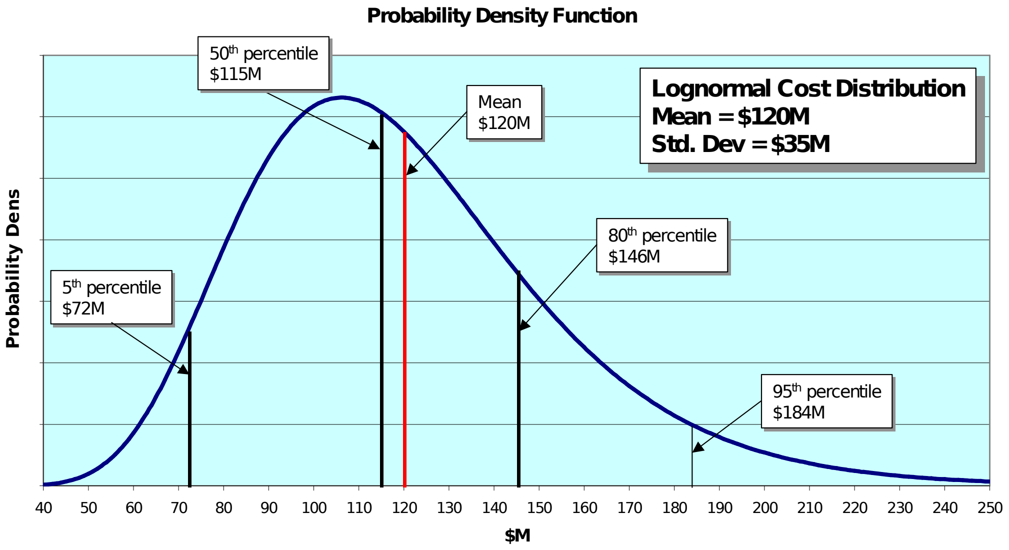
A	0.32
B	0.68

	2012	2013	2014	2015	2016	2017	2018	2019					
S	0.125	0.250	0.375	0.500	0.625	0.750	0.875	1.000					
F(S)	0.050	0.188	0.385	0.600	0.791	0.925	0.989	1.000					
Total Expended	$ 49.5	$ 187.9	$ 385.1	$ 600.0	$ 790.7	$ 924.6	$ 988.7	$ 1,000.0	$ -	$ -	$ -	$ -	$ -
Expenditure Profile (BY$)	$ 49.5	$ 138.3	$ 197.2	$ 214.9	$ 190.7	$ 133.9	$ 64.1	$ 11.3	$ -	$ -	$ -	$ -	$ -
Expenditure Profile (TY$)	$ 49.5	$ 142.6	$ 209.6	$ 235.5	$ 215.5	$ 156.0	$ 77.0	$ 14.0	$ -	$ -	$ -	$ -	$ -

Phasing a P^{th} Percentile Estimate and Re-Allocating Back to the WBS

Introduction

- So, you’ve established a cost estimate with a cost probability distribution…



- Now you have to decide what to report as “the estimate”
- Weapon Systems Acquisition Reform Act of 2009 suggests reporting the 80th percentile of the cost distribution as “the estimate”

Select the 80th Percentile

- Selecting the 80th percentile of the cost probability distribution is trivial
  - Compute it analytically, or
  - Select it from the @RISK output

- But, before phasing the 80th percentile, how do we allocate the extra margin (risk dollars) that this provides down to the individual WBS elements?

Calculate their 80th Percentiles Also?

- Seems fair enough…
  - If we are computing the 80th percentile of the total cost, why not do the same for the lower level WBS elements?

	Lognormal Distributions				
WBS Element	**Mean**	**CV**	**Sigma**		**80th**
Element 1	$ 77	17%	$ 13	→	$ 88
Element 2	$ 321	35%	$ 112	→	$ 403
Element 3	$ 417	19%	$ 79	→	$ 480
Element 4	$ 362	13%	$ 47	→	$ 400
Element 5	$ 165	37%	$ 61	→	$ 209
Total Cost	**$ 1,342**		**$ 171**		↓
80th %ile	**$ 1,482**		**Sum**	→	**$ 1,580**

  - Problem! The sum of the individual 80th percentiles is not equal to the 80th percentile of the sum

Okay…So Now What?

- How about allocating the risk dollars by pro-rating them among the WBS elements according to their relative cost?

	Lognormal Distributions				
WBS Element	**Mean**	**CV**	**Sigma**	**Allocation**	**Percentile**
Element 1	$ 77	17%	$ 13	$ 85.03	75%
Element 2	$ 321	35%	$ 112	$ 354.49	68%
Element 3	$ 417	19%	$ 79	$ 460.50	73%
Element 4	$ 362	13%	$ 47	$ 399.76	80%
Element 5	$ 165	37%	$ 61	$ 182.21	68%
Total Cost	**$ 1,342**		**$ 171**		
80th %ile	**$ 1,482**		**Sum →**	**$ 1,482**	

- That's easy enough to do, but it hardly seems fair
  - Each WBS element is estimated at a different percentile
  - Some are higher than others (68% - 80%)
  - Those with greater uncertainty have smaller percentiles, and vice versa

There Has to be a Better Way!

- We want the risk dollars (difference between the 80th percentile and the mean – in this case, $140) to be allocated to the lower level WBS elements in a way that is fair and makes sense
- Those WBS elements that have high uncertainty should be allocated a greater portion of the risk dollars than those that have low uncertainty
- Let’s try this!...allocate so that each WBS element is at the same percentile of its distribution AND the sum of the allocation is equal to the amount of risk dollars

A Straightforward Allocation Scheme

- In this example, each WBS element's cost is allocated to the 71st percentile

	Lognormal Distributions					
WBS Element	**Mean**	**CV**	**Sigma**		**Adjusted**	**Percentile**
Element 1	$ 77	17%	$ 13	→	$ 84	71%
Element 2	$ 321	35%	$ 112	→	$ 367	71%
Element 3	$ 417	19%	$ 79	→	$ 456	71%
Element 4	$ 362	13%	$ 47	→	$ 386	71%
Element 5	$ 165	37%	$ 61	→	$ 189	71%
Total Cost	**$ 1,342**		**$ 171**		↓	
80th %ile	**$ 1,482**		**Sum**	→	**$ 1,482**	

- The sum of the 71st percentiles is equal to the 80th percentile of the total cost estimate (in THIS example!)

Let's Look at the Differences

- Allocating each WBS element to the 80th percentile was FAIR, but was not CORRECT
  - Did not sum to the 80th percentile of the total cost estimate
- Allocating each WBS element by pro-rating to the individual costs was CORRECT, but was NOT FAIR
  - Because it did not properly adjust for differences in uncertainty
- Finally, allocating each WBS to the same percentile (71st in this case) was BOTH FAIR and CORRECT

	Lognormal Distributions			Allocations			Percent Deltas		
WBS Element	**Mean**	**CV**	**Sigma**	**80th**	**Pro-Rated**	**71st**	**80th**	**Pro-Rated**	**71st**
Element 1	$ 77	17%	$ 13	$ 87.5	$ 85.0	$ 83.5	14%	10%	8%
Element 2	$ 321	35%	$ 112	$ 403.3	$ 354.5	$ 367.1	26%	10%	14%
Element 3	$ 417	19%	$ 79	$ 480.0	$ 460.5	$ 455.7	15%	10%	9%
Element 4	$ 362	13%	$ 47	$ 400.3	$ 399.8	$ 386.2	11%	10%	7%
Element 5	$ 165	37%	$ 61	$ 209.2	$ 182.2	$ 189.5	27%	10%	15%
Total Cost	**$ 1,342**		**$ 171**						
80th %ile	**$ 1,482**		**Sum**	**$ 1,580**	**$ 1,482**	**$ 1,482**			

One More Wrinkle…Correlation

- WAIT!! We've forgotten something!
- If WBS element costs are correlated, then they "share" some of the responsibility for allocating the risk dollars
- How can we adjust for this?
  - We should adjust for it because the variance of the total cost distribution is larger than the sum of the variances of the underlying WBS elements – because of correlation!
  - Moreover, some WBS elements' variances contribute MORE to the total variance than others – because of correlation!

$$\sigma^2_{Total} = \sum_{j=1}^{n} \sum_{i=1}^{n} \rho_{ij} \sigma_i \sigma_j$$

The Correlation Matrix

- In order to correlate WBS elements in a cost estimate, one needs to create a matrix that lists the inter-element correlations, such as:

Correlations	Element 1	Element 2	Element 3	Element 4	Element 5
Element 1	**1.0**	0.2	0.4	0.8	0.2
Element 2	0.2	**1.0**	0.3	0.2	0.5
Element 3	0.4	0.3	**1.0**	0.2	0.3
Element 4	0.8	0.2	0.2	**1.0**	0.2
Element 5	0.2	0.5	0.3	0.2	**1.0**

- The entry in row i and column j is denoted rij
- All correlation entries are such that ($-1.0 \leq \rho_{ij} \leq +1.0$) with 1's on the diagonal

Computing Total Variance

- To compute the variance of the total cost, one must include the correlation matrix

$$\sigma_{Total}^{2} = \sum_{j=1}^{n} \sum_{i=1}^{n} \rho_{ij} \sigma_i \sigma_j$$

- Using matrix algebra, this can be computed as

$$\sigma_{Total}^{2} = \sigma \rho \sigma^{T} = \sum_{j=1}^{n} \sum_{i=1}^{n} \rho_{ij} \sigma_i \sigma_j$$

- Where σ represents the standard deviation vector and ρ represents the correlation matrix

Computing the Associated Variance of WBS Element *k*

- The portion of the total cost variance that is associated, either directly or via correlation, with WBS element *k* is given by the following expression:

$$\sigma^2_{Assoc(k)} = \sum_{i=1}^{n} \rho_{ik}\sigma_i\sigma_k = \sigma_k \rho_k \sigma^T$$

- Where σ_k is a constant representing the standard deviation of WBS element *k*, σ represents the standard deviation vector, and ρ_k represents the k^{th} row of the correlation matrix

An Even Better Allocation Scheme

- If we consider correlation, then the *fraction* of *risk dollars* to be allocated to WBS element *k* should therefore be

$$\frac{\sigma^2_{Assoc(k)}}{\sigma^2_{Total}} = \frac{\sum_{i=1}^{n} \rho_{ik}\sigma_i\sigma_k}{\sum_{j=1}^{n}\sum_{i=1}^{n} \rho_{ij}\sigma_i\sigma_j} = \frac{\sigma_k \rho_k \sigma^T}{\sigma \rho \sigma^T} = \frac{\text{UncertaintyPortion for } k}{\text{UncertaintyBase}}$$

- And the *amount* of *risk dollars* allocated to WBS element *k* is therefore

$$\frac{\sum_{i=1}^{n} \rho_{ik}\sigma_i\sigma_k}{\sum_{j=1}^{n}\sum_{i=1}^{n} \rho_{ij}\sigma_i\sigma_j} \times \text{TotalAmountofRiskDollar}$$

Example: Compute Total Variance

- The Total Variance is computed in Excel as follows:

{=mmult(transpose(SIGMA),mmult(CORRMATRIX,SIGMA))}

- Where SIGMA is the column of individual WBS elements standard deviations and CORRMATRIX is the correlation matrix

SIGMA

	Lognormal Distributions		
WBS Element	**Mean**	**CV**	**Sigma**
Element 1	$ 77	17%	$ 13
Element 2	$ 321	35%	$ 112
Element 3	$ 417	19%	$ 79
Element 4	$ 362	13%	$ 47
Element 5	$ 165	37%	$ 61
Total Cost	**$ 1,342**		**$ 218**

Total Variance: **47,594** ← **Total Variance**

Correlations	Element 1	Element 2	Element 3	Element 4	Element 5
Element 1	**1.0**	0.2	0.4	0.8	0.2
Element 2	0.2	**1.0**	0.3	0.2	0.5
Element 3	0.4	0.3	**1.0**	0.2	0.3
Element 4	0.8	0.2	0.2	**1.0**	0.2
Element 5	0.2	0.5	0.3	0.2	**1.0**

CORRMATRIX

- The Total Variance serves as the “Uncertainty Base” in the risk dollar allocation

Example: Compute Associated Variance of WBS Element k

- The Associated Variance of WBS element k is computed in Excel as follows:
  {=SIGMA(k)*mmult(CORRMATRIX(k),SIGMA)}
- Where SIGMA is the column of individual WBS elements standard deviations, SIGMA(k) is a scalar representing the kth Standard Deviation, and CORRMATRIX(k) is the kth row of the correlation matrix

SIGMA

	Lognormal Distributions		
WBS Element	**Mean**	**CV**	**Sigma**
Element 1	$ 77	17%	$ 13
Element 2	$ 321	35%	$ 112
Element 3	$ 417	19%	$ 79
Element 4	$ 362	13%	$ 47
Element 5	$ 165	37%	$ 61
Total Cost	**$ 1,342**		**$ 218**

Total Variance: 47,594

Correlations	Element 1	Element 2	Element 3	Element 4	Element 5
Element 1	**1.0**	0.2	0.4	0.8	0.2
Element 2	0.2	**1.0**	0.3	0.2	0.5
Element 3	0.4	0.3	**1.0**	0.2	0.3
Element 4	0.8	0.2	0.2	**1.0**	0.2
Element 5	0.2	0.5	0.3	0.2	**1.0**

SIGMA(3) **CORRMATRIX(3)**

- The Associated Variance of WBS element k serves as the “Uncertainty Portion for k” in the risk dollar allocation

Example: Resulting Allocation

- Finally, the Risk Dollars are allocated according to the ratio of the Associated Variance of WBS Element k versus the Total Variance

$$\frac{\sum_{i=1}^{n} \rho_{ik}\sigma_i\sigma_k}{\sum_{j=1}^{n}\sum_{i=1}^{n} \rho_{ij}\sigma_i\sigma_j} \times \text{Total Amount of Risk Dollar}$$

WBS Element	Lognormal Distributions Mean	CV	Sigma	Assoc Variance	Pct Allocation	Risk Dollars	Adjusted Cost
Element 1	$ 77	17%	$ 13	**1,533**	**3%**	**$ 6**	**$ 83**
Element 2	$ 321	35%	$ 112	**20,074**	**42%**	**$ 74**	**$ 395**
Element 3	$ 417	19%	$ 79	**11,559**	**24%**	**$ 43**	**$ 460**
Element 4	$ 362	13%	$ 47	**5,085**	**11%**	**$ 19**	**$ 381**
Element 5	$ 165	37%	$ 61	**9,342**	**20%**	**$ 34**	**$ 199**
Total Cost	**$ 1,342**		**$ 218**	**47,594**		**$ 175**	**$ 1,517**
80th Percentile	**$ 1,517**						
Risk Dollars	**$ 175**						

The sum of the individual WBS Element costs is equal to the 80th Percentile of the total cost

A Brief Caveat

- The methods I have just described assume that the cost distributions are either symmetric or right-tailed (e.g., lognormal) and that the point estimate is less than the 80th (or whatever) percentile
- Dr. Steve Book of MCR has shown how to allocate based on "need" under some arcane circumstances when the previous assumptions do not hold[1]
  - For example, left-tailed triangular distributions mess things up because, under certain circumstances, they can cause one to allocate NEGATIVE dollars to certain WBS elements
  - This is a significantly more complicated procedure and will require a training class of its own
  - While Dr. Book's method is sound, and technically correct, it will not be covered in this lecture because its assumptions are seldom seen in practice
  - Today's method is practical and fairly simple!

[1] S.A. Book, "Allocating "Risk Dollars" Back to Individual Cost Elements," NELO, 2007

Risk Dollar Allocation Instructions

- From @RISK Results, find MEAN and STD DEV of each WBS element cost
  - Also find the MEAN and STD DEV of the TOTAL cost
- From @RISK, determine the pth percentile of the TOTAL cost (where p = 70%, 80%, or whatever is desired)
- Subtract the MEAN TOTAL cost from the pth percentile of the TOTAL cost
  - This represents the Risk Dollars that you want to allocate
- Compute the Associated Variance of each WBS element using the correlation matrix
- Compute the percent allocation for each WBS element
  - Ratio of Associated Variance to Total Variance
- Multiply the TOTAL Risk Dollars by the percent allocation to arrive at the Risk Dollar allocation to each WBS element
- Add the Risk Dollar allocation to each WBS element's MEAN cost
- Finally, phase the 80th percentile estimate in the same way described previously

Risk Dollar Allocation Demo

	From @RISK Results		Computed Values			
WBS Element	**Mean**	**Sigma**	**Assoc Variance**	**Percent Allocation**	**Risk Dollars**	**Risk Adjusted Cost**
Element 1	$ 77.0	$ 13.1	1,533	3.2%	$ 5.6	$ 82.6
Element 2	$ 321.0	$ 112.4	20,074	42.2%	$ 73.8	$ 394.8
Element 3	$ 417.0	$ 79.2	11,559	24.3%	$ 42.5	$ 459.5
Element 4	$ 362.0	$ 47.1	5,085	10.7%	$ 18.7	$ 380.7
Element 5	$ 165.0	$ 61.1	9,342	19.6%	$ 34.4	$ 199.4
Total Cost	**$ 1,342.0**	**$ 218.0**	**47,594**	**100.0%**	**$ 175.0**	**$ 1,517.0**

The Correlation Matrix that was used for @RISK

Correlations	Element 1	Element 2	Element 3	Element 4	Element 5
Element 1	**1.0**	0.2	0.4	0.8	0.2
Element 2	0.2	**1.0**	0.3	0.2	0.5
Element 3	0.4	0.3	**1.0**	0.2	0.3
Element 4	0.8	0.2	0.2	**1.0**	0.2
Element 5	0.2	0.5	0.3	0.2	**1.0**

Total Variance	**47,594**	**Computed Value**
pth Percentile	**$ 1,517.0**	**from @RISK Results**
Risk Dollars	**$ 175.0**	**Computed Value (difference between pth percentile and Mean)**

Allocation Example.xls

Summary

- What we have covered today:
  - Various methods used to phase cost estimates
  - Converting a cost profile to a budget profile
  - How to allocate a p^{th} percentile cost estimate back to the WBS so that they all add up correctly

Reading and Homework

- For this week:
  - Do Homework Assignment 8 in Sakai
    - “Phasing Homework.doc”